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Computational performance of risk-based inspection methodologies for offshore wind support structures

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Offshore wind turbines are dynamically responding structures reaching around 70 million of stress cycles per year due to the combined action of waves and wind loading. Therefore, the assessment of fatigue deterioration becomes crucial. Besides, fatigue assessment is characterized by large uncertainties associated with both fatigue loads and strength. Inspections can be undertaken to detect potential cracks and therefore improve our belief about the condition of the structure.

However, offshore wind inspections are costly and complex operations, involving the deployment of ROVs or divers for the case of underwater components. Risk-based inspection aims to identify the optimal maintenance policy by balancing the risk of structural failure against maintenance efforts (inspections and repairs). Introduction of a risk-based inspection plan can lead to reductions in the expected life-cycle costs as already demonstrated in the Oil & Gas sector.

Inspection planning is a complex sequential decision problem where the decision about whether to go or not for an inspection must consider the outcomes from the previous inspections. In theory, it is possible to find the optimal policy by solving a pre-posterior decision analysis, as defined by Raiffa¹. Nevertheless, for the real case of an offshore wind structure standing a lifetime of 20 years, it is not possible to solve a decision tree which is exponentially growing over time and it becomes computationally intractable.

Due to the computational limitations, assumptions are generally introduced within the risk-based analysis leading to approximate optimal policies. Traditional risk-based inspection techniques encompass FORM/SORM or Monte Carlo simulations to estimate and update the probability of failure as well as the inclusion of heuristic decision rules to solve the decision problem. However, novel methods and algorithms have been proposed recently to improve the computational efficiency of the risk-based analyses such as Dynamic Bayesian Networks (DBNs) or Partially Observable Markov Decision Processes (POMDPs).

The aim of this work is to compare the existing risk-based inspection planning methodologies applicable to offshore wind structures. The computational performance and life-cycle expected costs corresponding to the different methodologies are explored. Additionally, the challenges which risk-based inspection planning is facing in the present are presented and potential solutions are suggested, for instance, on how to incorporate the correlation between structural components or “system-effects” into the risk-based analysis.

In order to explore the main aspects involved during the application of the existing risk-based methodologies, the following steps are pursued: 1) identification of the most relevant random variables within the deterioration models, 2) calibration of SN/Miner’s fatigue model to a fracture mechanics model, 3) comparison of the methods available for updating the failure probability when information from inspections is available and 4) comparison of the methods available to solve the pre-posterior decision problem corresponding to inspection planning.

The optimal inspection plan for an offshore wind tubular joint is then identified by employing the different risk-based methodologies. Thereby, the methodologies are reviewed in terms of: 1) computational time to set up the model, 2) computation time required by the simulation and 3) obtained life-cycle expected costs. The results highlight the computational advantages of modern methods such as DBNs or POMDP which facilitate the identification of more optimal inspection policies.

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[1] Schlaifer and Raiffa (1961).